(54) Title: SIGNAL TRANSMISSION CIRCUIT FOR PROBE
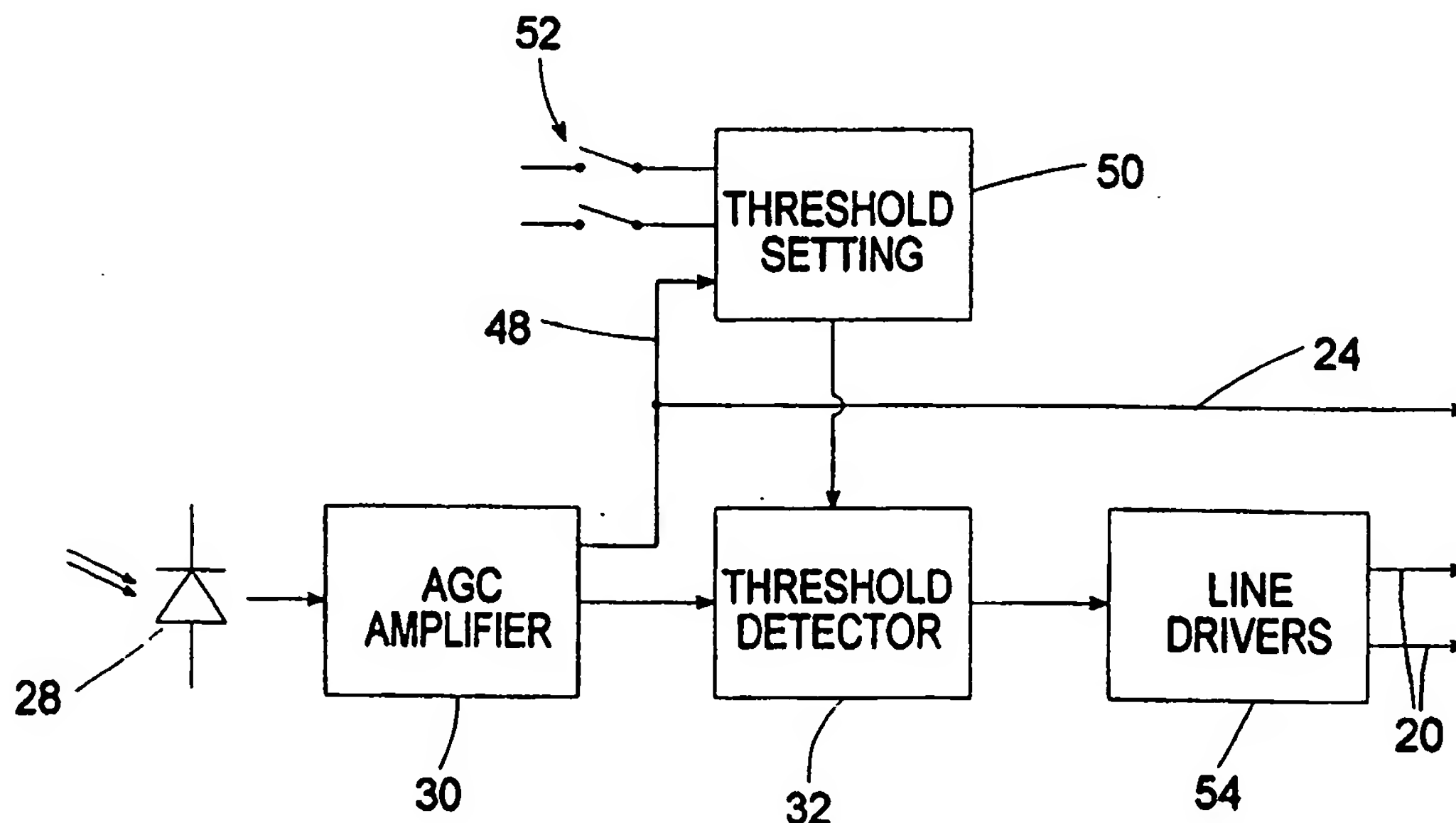
(57) Abstract

An optical pulse signal from a machine tool measuring probe is received by a photodiode (28). To reduce interference from xenon strobe beacons, fluorescent lights etc., the pulse signal is processed by an AGC amplifier (30) with low frequency signal cancellation, and the pulses are then detected by a threshold detector (32). The threshold of this detector (32) is variable by a circuit (50), in accordance with the overall amplitude of the signal pulses, in order to provide the best rejection of interference pulses.

SIGNAL TRANSMISSION CIRCUIT FOR PROBE

This invention relates to a signal transmission circuit.
It may be used for the signal generated by a probe of the
type used for measurement on position determining machines
such as machine tools.

It is known to insert a measuring probe into the movable
spindle of a machine tool, so that the spindle may bring
the probe into contact with various surfaces of a workpiece
to be measured. Since the probe is exchangeable for
cutting tools, it is difficult or impossible to hardwire
the probe to the subsequent interface circuit which
processes the signal and interfaces it to the machine
control. Consequently, various wireless signal
transmission systems are known. These may, for example,
transmit the signals optically or by radio to a receiver
mounted on the fixed structure of the machine.

As the spindle-mounted probe moves around the machine, the
signal strength received by the receiver varies.
Particularly in the case of optical transmission systems,
it is known to provide two or more receivers, at different
locations on the machine, so that if the signal received by
one is weak or non-existent, nevertheless a good signal is
received by the other. In such known arrangements, the
circuit in the interface simply combines the outputs from
the two receivers in parallel.

It is desired to make signal transmission systems which are
usable even on large machines, and on machines where there
may not always be a line of sight between the probe and one
of the receivers. To some extent, this can be achieved by
increasing the power output of the probe's transmitter.
This increases the range of the signal transmission system.
In the case of optical systems, it also allows the use of
light which is reflected from various surfaces of the
machine even when there is no line of sight. However, in

practice, there is a limit to such increases in power, because the probe is battery-operated. If a very high power is emitted, the battery life will be very short. Another possibility, therefore, is to increase the receiver
5   sensitivity.

Problems arise, however, both with single receivers and multiple receivers, if the receivers are made more sensitive so as to extend the range of the signal transmission. The greater sensitivity renders the
10 receivers more susceptible to interference. In the case of optical systems, such interference may be caused by strobe beacons, fluorescent lights, or even other signal transmission systems of probes on nearby machines.

One aspect of the present invention provides a signal
15 transmission circuit for a probe, in which the probe signal is transmitted in the form of pulses, and comprising a circuit for receiving said pulses,
        wherein the pulse receiving circuit includes a threshold detector which produces an output when a said
20 pulse exceeds a given threshold, said threshold being variable in accordance with the amplitude of the pulses received,
        and wherein the value of said given threshold decays when the signal level falls below the threshold, with a
25 time constant which is large compared to the pitch of the pulses but small compared to fluctuations in the overall amplitude of the pulses.

A second aspect of the invention provides a signal transmission system for a probe, comprising:
30   a transmitter associated with the probe;
        a plurality of receivers for receiving signals transmitted by the transmitter;
        a circuit connected to receive the output signals of said receivers;
35   said circuit comparing the signal strengths of the

signals from each receiver and selecting an output from one
or more of the receivers based on the relative signal
strengths thereof.

A preferred embodiment of the invention will now be
described by way of example, with reference to the
accompanying drawings wherein:

    Fig 1 is an overall schematic diagram of a machine
tool probe and a signal transmission system;

    Fig 2 is a schematic circuit diagram of a receiver
shown in Fig 1;

    Fig 3A and 3B are graphs of signals, for explaining
the operation of the receiver circuit of Fig 2;

    Fig 4 shows a circuit which forms part of an interface
seen in Fig 1; and

    Fig 5 is a schematic diagram of an alternative
receiver to that of Fig 2.

Fig 1 shows a probe 10 which can be mounted in the spindle
of a machine tool for movement in X,Y and Z directions (as
indicated by arrows 12). The probe is suitably a touch
trigger probe with a deflectable stylus 14, which issues a
trigger signal when its stylus 14 contacts a workpiece.
However, the invention is also useful for probes which
output a signal corresponding to the amount of deflection
of the stylus 14. The signal is transmitted optically to
the machine control from the probe and to this end the
probe 10 has a plurality of light emitting diodes 16 (for
example, red or infra-red light emitting diodes). The
probe is battery-powered, and when switched on it emits a
continuous stream of light pulses, onto which the required
signals are encoded.

The light pulses are received by photodetectors 28,28' in
one or more receiving units (two of which are shown at 18
and 18' in the present example). Each receiver converts
the light pulses to two complementary electrical pulse
signals, which are sent on lines 20,20' to an interface

circuit 22. Each receiver 18,18' also produces a DC level
on a line 24,24', which indicates the amplitude or signal
strength of the light pulses received. The DC level may be
a voltage level or a current level. This DC signal is also
5   taken to the interface 22.

After processing the signals, the interface 22 produces an
output signal on a line 26, which is sent to the machine
control. In the case of a touch trigger probe, the line 26
carries a trigger signal indicating that the stylus 14 has
10 touched a workpiece, and the machine control uses this to
halt the movement of the probe and to initiate a
determination of the probe's position in space (and hence
of the position of the workpiece surface). Alternatively,
the interface 22 can output a signal corresponding to the
15 amount of deflection of the stylus 14.

As the probe 10 moves around the machine, the signal level
received by a given one of the receivers 18,18' will vary,
depending on the relative position of the probe and the
receiver. However, as in previously known arrangements,
20 the intention is that, at any given time, at least one of
the receivers 18 will receive a useable signal.

The range of the signal transmission system is improved
(compared to previously known arrangements) partly by
increasing the power output of the diodes 16, but mainly by
25 increasing the sensitivity of the receivers 18,18'.
Naturally, however, this also makes them more sensitive to
unwanted interference, such as from xenon strobe beacons,
fluorescent lights and the signal transmission systems of
probes on nearby machines. Arrangements which enable one
30 or more of these problems to be reduced or overcome will
now be described.

Fig 2 shows schematically the circuit of one of the
receivers 18. The other receiver 18' is similar. The
infra-red light pulses are received by a photodiode 28, and

processed by an amplifier 30. This includes an automatic
gain control (AGC) and has a high pass characteristic. The
amplifier thus provides low frequency signal cancellation,
to remove the effects of sunlight, low frequency lighting,
5   and other background light. It also produces an automatic
gain control output on a line 48, which is indicative of
the amplitude of the incoming pulses. This output also
provides the DC level on the line 24 to the interface 22.

Next, the variable amplitude pulse signals which are output
10   from the amplifier 30 are taken to a threshold detector 32.
The effect of this is explained in Figs 3A and 3B.

In Fig 3A, curve 34 indicates the output of the amplifier
30, and curve 38 represents the output of the threshold
detector 32. The curve 34 includes pulses 36 which are the
15   required signal transmitted from the probe 10. Each of
these pulses 36, as can be seen, has a trailing tail, and
the effect of the threshold detector 32 is to square the
pulses up, as seen at 40 in the curve 38. A broken line 42
in Fig 3A indicates the variable nature of the threshold of
20   a previously known, commercially available device. In this
known device, the threshold rises stepwise on the leading
edge of each pulse 36. (The rise is in the negative
direction since the pulses are negative-going.) This
prevents the output pulses 40 from becoming too wide as a
25   result of the tail of the pulse 36. However, the threshold
in this known device falls immediately after each pulse 36,
with a relatively short time constant, ready for the next
pulse 36. (The fall in the threshold is in the positive
direction in Fig 3A.) The threshold 42 of the known device
30   in Fig 3A has a certain minimum level, i.e. a certain
minimum distance in the negative direction from the base
line of the curve 34.

It was mentioned above that the sensitivity of the receiver
18 has been increased, compared to the known, commercially
35   available devices. Of course, one result of this is that

it is more susceptible to interference. This can be seen
in Fig 3A, where interference pulses are shown at 44. In
the previously known device, these interference pulses
would be quite small, but in Fig 3A they are of a

5   significant size because of the increased sensitivity. As
a result, the interference pulses 44 can exceed (in the
negative-going direction) the threshold level 42. This
results in spurious, error pulses 46 in the output curve
38.

10 To overcome this problem, the known device is modified as
shown in Fig 3B. Here, the threshold is indicated by a
broken line 42A. As in Fig 3A, it rises stepwise (in the
negative direction) on receipt of the first pulse 36.
However, it decays with a significantly longer time

15 constant than the threshold 42 in Fig 3A. Consequently, as
long as other pulses 36 continue to be received from the
probe 10, the threshold 42A exceeds the interference pulses
44 (in the negative direction) and no error pulses 46
appear in the output 38.

20 In Fig 3B, it might appear as if the threshold 42A has a
constant level after the first pulse 36. However, it does
decay gradually, with a relatively long time constant
compared to the time between the pulses 36. This time
constant is still chosen to be short compared with the time

25 taken for the probe 10 to move from one side of the machine
to the other (i.e. closer to one receiver 18 and further
away from the other). Thus, as the probe moves away from
the corresponding receiver 18, the threshold 42A falls
(i.e. becomes more positive). This ensures that the signal

30 pulses 36 (which are of course now reduced in amplitude)
continue to exceed the threshold and produce output pulses
40.

Fig 2 shows the remainder of the circuitry for producing
this effect. The threshold 42A is set in a threshold

35 setting circuit 50, based upon the automatic gain control

output 48 received from the amplifier 30. The circuit 50
also receives inputs from preset switches 52. These
switches 52 enable the setting of the minimum level of the
threshold 42A in the absence of the input pulses 36 (i.e.

5   the level shown at 42B in Fig 3B). Setting these presets
is undertaken for each machine tool installation, depending
on the level of interference experienced, in order to
ensure that the threshold detector 32 has the greatest
possible sensitivity to the required signal pulses, while

10 not being overly sensitive to interference.

The pulses 40 output from the threshold detector 32 are
used to feed line drivers 54. This produces the
complementary pulse signals on the lines 20 to the
interface 22.

15 The interface circuit 22 contains circuitry which decodes
the pulse signals in order to produce the output 26
representing the probe signal (e.g. a touch trigger signal
when the stylus 14 contacts a workpiece). Additionally,
however, it also contains the circuitry shown in Fig 4.

20 Fig 4 shows the lines 20 and 20' which carry the
complementary pulse inputs from the respective receivers
18,18'. The complementary signals from each receiver are
combined, e.g. by differential amplifiers 25,25' and are
buffered by a corresponding field effect transistor T1,T1'.

25 They then appear on respective lines 56,56' for subsequent
processing, during which they are combined together, as
illustrated schematically by a combiner circuit 58.

The DC signals 24,24' from the two receivers 18,18' are
each taken to the non-inverting input of a respective

30 comparator 60,60' via resistors R1,R1'. Additionally, the
two DC levels 24,24' are combined and averaged by
respective resistors R2,R2' and a resistor R3. This
average value is taken to the inverting input of each of
the comparators 60,60'. Thus, when either of the DC

signals 24,24' is above the average, its corresponding
comparator 60,60' turns on a respective field effect
transistor T2,T2'. This enables the corresponding
transistor T1,T1' so that the corresponding pulse signals
5   from the lines 20 or 20' are fed to the combiner 58 and the
subsequent processing circuitry. Conversely, if a given
signal 24,24' is below the average value, the corresponding
transistor T2,T2' is turned off, inhibiting the respective
transistor T1,T1' so that the pulses on the lines 20 or 20'
10   do not feed through to the combiner 58.

The values of the resistors R2,R2' and R3 are selected such
that the average value fed to the inverting inputs of the
comparators 60,60' is in fact slightly below the true
arithmetical mean of the signals on the lines 24,24'.
15   Thus, if the signals on the lines 24,24' are approximately
equal, both transistors T2,T2' will be switched on and the
signals on both the lines 20 and the lines 20' will be
combined in the combiner 58. If one of the signal levels
24,24' is significantly greater than the other, then only
20   the corresponding pair of the inputs 20,20' will be enabled
and the other will be disabled. As a result, the weaker
signal (which is more likely to be subject to interference)
is disabled and is not used by the subsequently processing
circuitry. Furthermore, it will be appreciated that, by
25   setting the average slightly below the strict arithmetical
mean, it is ensured that both pairs of signals 20,20' are
never disabled at the same time.

The circuit is easily extended to an installation in which
three or more receivers 18 are provided. For each receiver
30   18, there is a corresponding comparator 60 and transistors
T1,T2. The inverting inputs of each comparator 60 receive
a DC level which results from averaging the DC levels on
the lines 24 from all the receivers 18.

Fig 5 shows a development of the circuit of Fig 2. It has
35   a number of similar elements, including AGC amplifier 30,

threshold detector 32 and line drivers 54, which process
the incoming light pulses in a similar manner to the
corresponding elements in Fig 2. This circuit illustrates
that the DC level on the line 24 may be provided by a peak
5   detector circuit 70 (the output of which is held and which
then decays with a suitable time constant, longer than the
pulse spacing) instead of from the AGC amplifier 30.

The threshold setting circuit 50 comprises two further peak
detectors 72,74 in series. The output of the peak detector
10 72 decays with a relatively short time constant (e.g. about
3.3ms). It provides an output pulse which is long enough
to charge the next peak detector 74. The output of the
peak detector 74 raises the threshold of the threshold
detector 32, and decays with a relatively long time
15 constant (e.g. 103ms). The effect is similar to that
described above with reference to Fig 3B, except the peak
value is taken from the second pulse as described later.

A sensitivity setting circuit 76 may include a programmable
voltage divider with switches like the switches 52 in Fig
20 2. This circuit 76 varies the minimum level to which the
peak detectors 72,74 can discharge, and thus varies the
minimum threshold 42B of the threshold detector 32, as
previously.

The Fig 5 threshold setting circuit 50 differs in two
25 significant respects from that of Fig 2. Firstly, a
timeout circuit 78 is reset by each output pulse from the
threshold detector 32. Should there be no such output
pulse for a given period of time (substantially longer than
the pitch of the incoming light signal pulses - e.g. 18ms)
30 then the timeout circuit 78 quickly discharges the peak
detector 74, via an FET 79. This reduces the threshold to
its minimum setting, resulting in maximum sensitivity of
the threshold detector 32. Thus, if the probe 10 is moved
so that there is no longer a direct line of sight to the
35 photodiode 28, maximum sensitivity is restored quickly so

that the circuit can respond to reflected light pulses.

The other significant difference is a time window generator
80, also connected to the output of the threshold detector
32. This generates a time window which is slightly longer
5   than the spacing between two adjacent signal pulses,
suitably 22μs. The time window generator 80 controls an
electronic switch e.g. in the form of a field effect
transistor 82. In the absence of signal pulses, this
switch is normally on, and inhibits the input to the peak
10 detector 72.

The purpose of the time window generator 80 is to
distinguish between genuine signal pulses and interference
pulses, e.g. from xenon beacons or fluorescent lights,
which are longer than the chosen time window. When a
15 genuine pulse is followed by a second genuine pulse within
the time window, this turns off the transistor 82 briefly,
enabling the peak detectors 72,74 so that they react to the
second genuine pulse and set the threshold in accordance
with its amplitude. Continuing genuine signal pulses
20 ensure that the peak detectors 72,74 continue to be enabled
briefly for each successive pulse. In the event of an
interference pulse longer than the time window, the
transistor 82 remains on so that the peak detectors are
disabled. In this way, the interference pulse does not
25 increase the threshold setting, and succeeding signal
pulses are correctly detected by the threshold detector 32.
Of course, the interference pulse passes through the line
drivers 54 to the interface 22, but the pulse decoding
circuitry in the interface 22 can recover from the
30 resulting error with the aid of the succeeding signal
pulses which are unaffected.

The arrangements described can be modified for use with
other wireless signal transmission systems, e.g. radio
systems.

CLAIMS

1.   A signal transmission circuit for a probe, in which
the probe signal is transmitted in the form of pulses, and
comprising a circuit for receiving said pulses,

5   wherein the pulse receiving circuit includes a
threshold detector which produces an output when a said
pulse exceeds a given threshold, said threshold being
variable in accordance with the amplitude of the pulses
received,

10   and wherein the value of said given threshold decays
when the signal level falls below the threshold, with a
time constant which is large compared to the pitch of the
pulses but small compared to fluctuations in the overall
amplitude of the pulses.

15 2.   A circuit according to claim 1, including a circuit
which detects the amplitude of the received pulses, and
wherein the threshold of the threshold detector is varied
in accordance with an output signal from said amplitude
detecting circuit.

20 3.   A circuit according to claim 2, wherein the amplitude
detecting circuit is an amplifier for the received pulses,
which includes an automatic gain control.

4.   A circuit according to claim 2, wherein the amplitude
detecting circuit is a peak detector which detects a peak
25 value of a received pulse.

5.   A circuit according to claim 2, claim 3 or claim 4,
wherein the amplitude detecting circuit resets the
threshold to a minimum setting if no signal pulse is
received within a given time period.

30 6.   A circuit according to claim 2, claim 3, claim 4 or
claim 5, including a circuit for detecting an interference
pulse which is longer than a signal pulse, and which

inhibits the setting of the threshold if an interference
pulse is detected.

7.   A circuit according to claim 1 or claim 2, including
an amplifier for the received pulses, which includes an
automatic gain control.

8.   A circuit according to any one of the preceding
claims, including an amplifier for the received pulses,
which provides low frequency signal cancellation.

9.   A circuit according to any one of the preceding
claims, including a circuit for presetting the minimum
level of the threshold.

10.   A signal transmission system for a probe, comprising:
      a transmitter associated with the probe;
      a plurality of receivers for receiving signals
transmitted by the transmitter;
      a circuit connected to receive the output signals of
said receivers;
      said circuit comparing the signal strengths of the
signals from each receiver and selecting an output from one
or more of the receivers based on the relative signal
strengths thereof.

11.   A system according to claim 10, wherein the circuit
which receives and compares the receiver output signals
includes a circuit for combining and averaging the receiver
output signals, and for selecting an output signal when it
exceeds the average.

12.   A system according to claim 11, wherein the average
value used by said circuit is below the true arithmetical
mean of the receiver output signals, so that more than one
signal is selected if the signals are approximately equal.

13.   A system according to claim 10, claim 11 or claim 12,

including a circuit according to any one claims 1 to 9 for
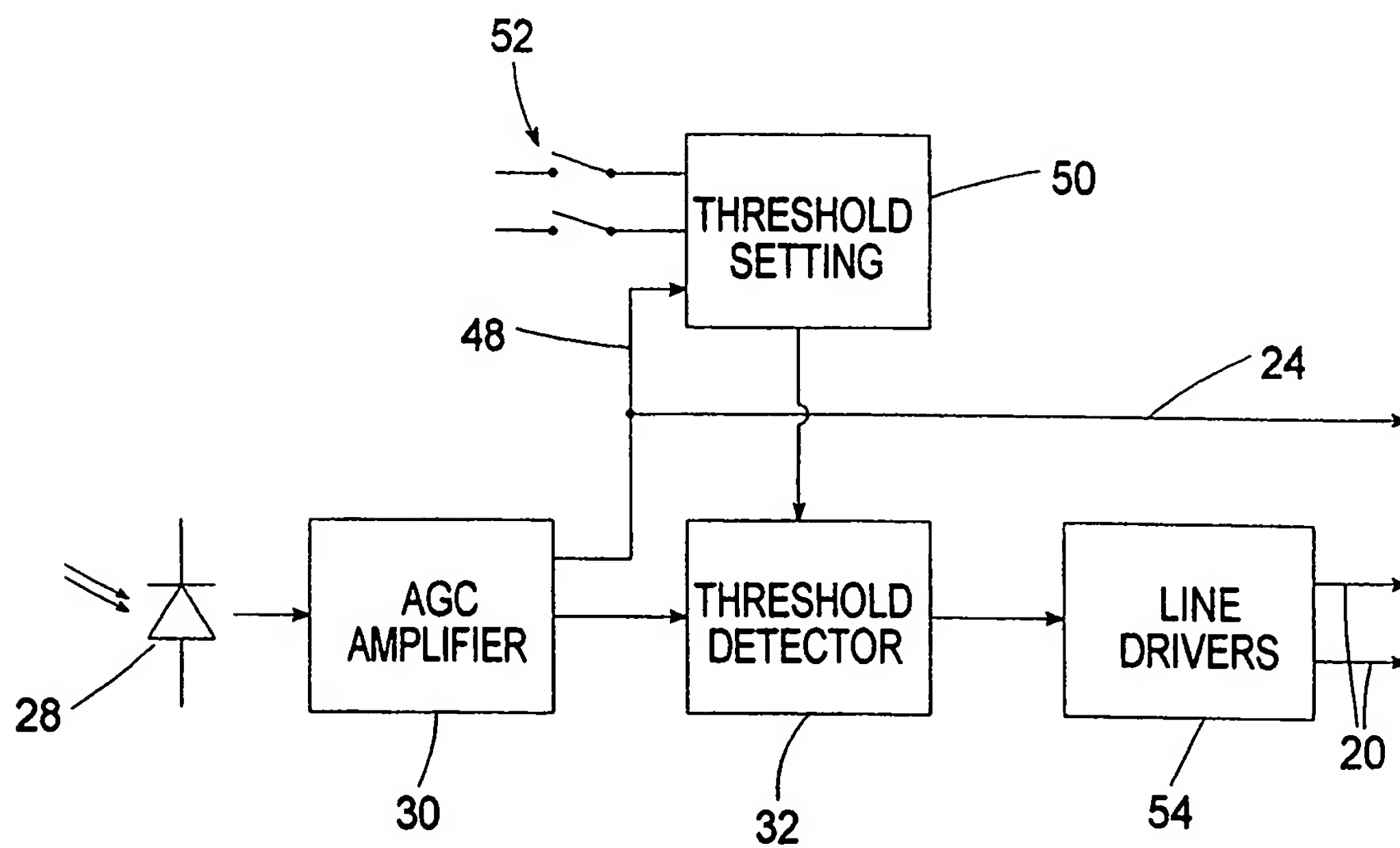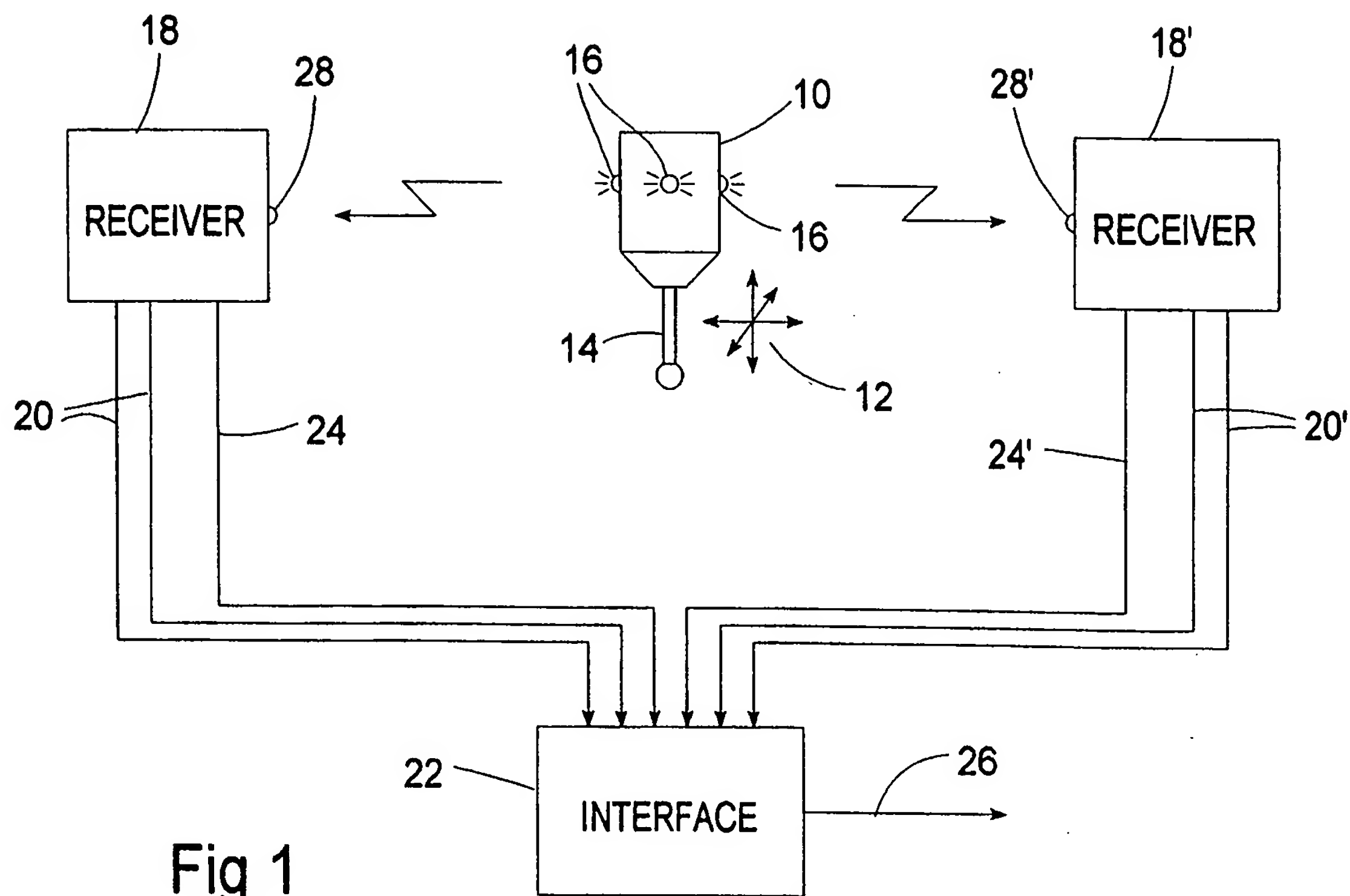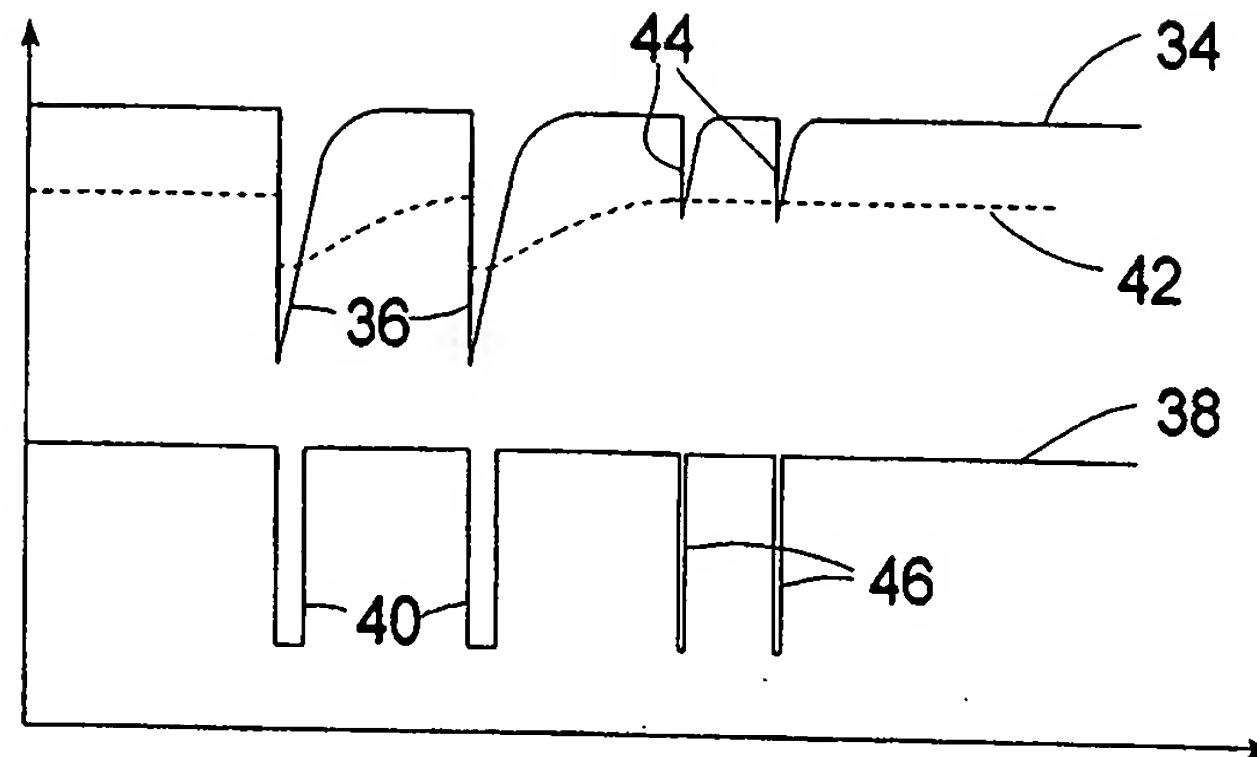processing the signal received by a said receiver.

Fig 1

Fig 2

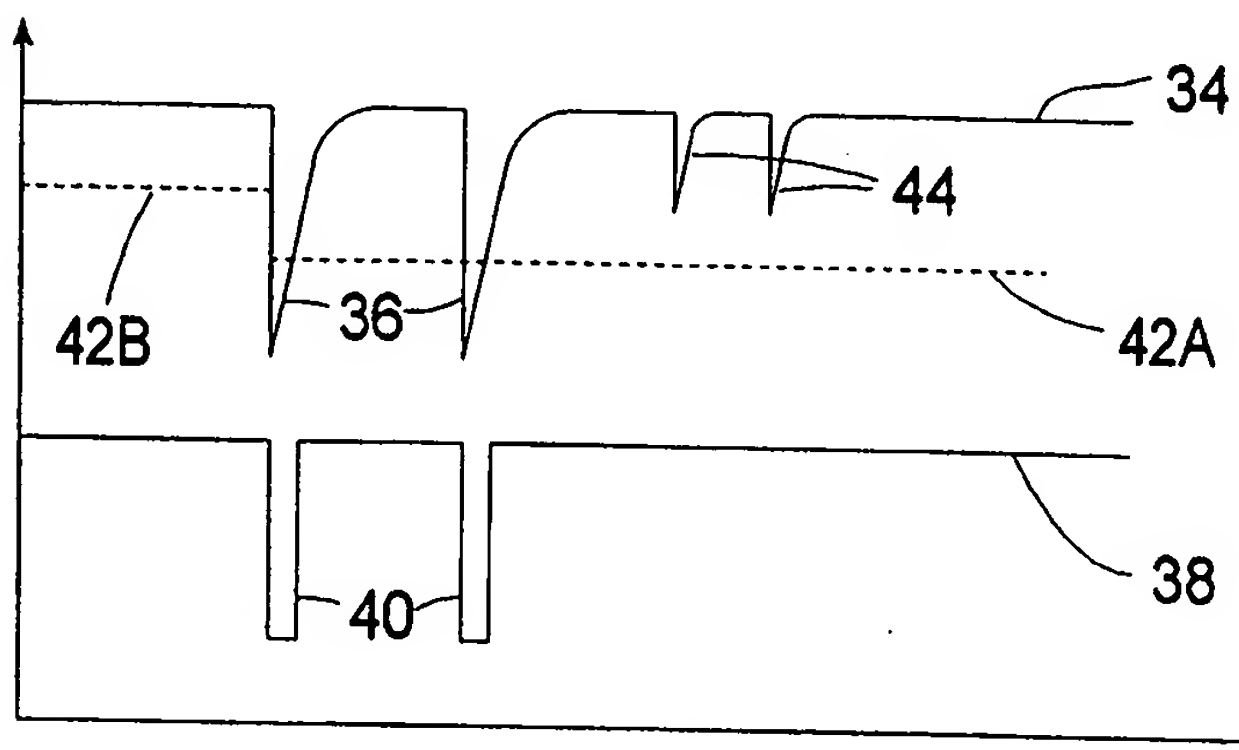Fig 3A
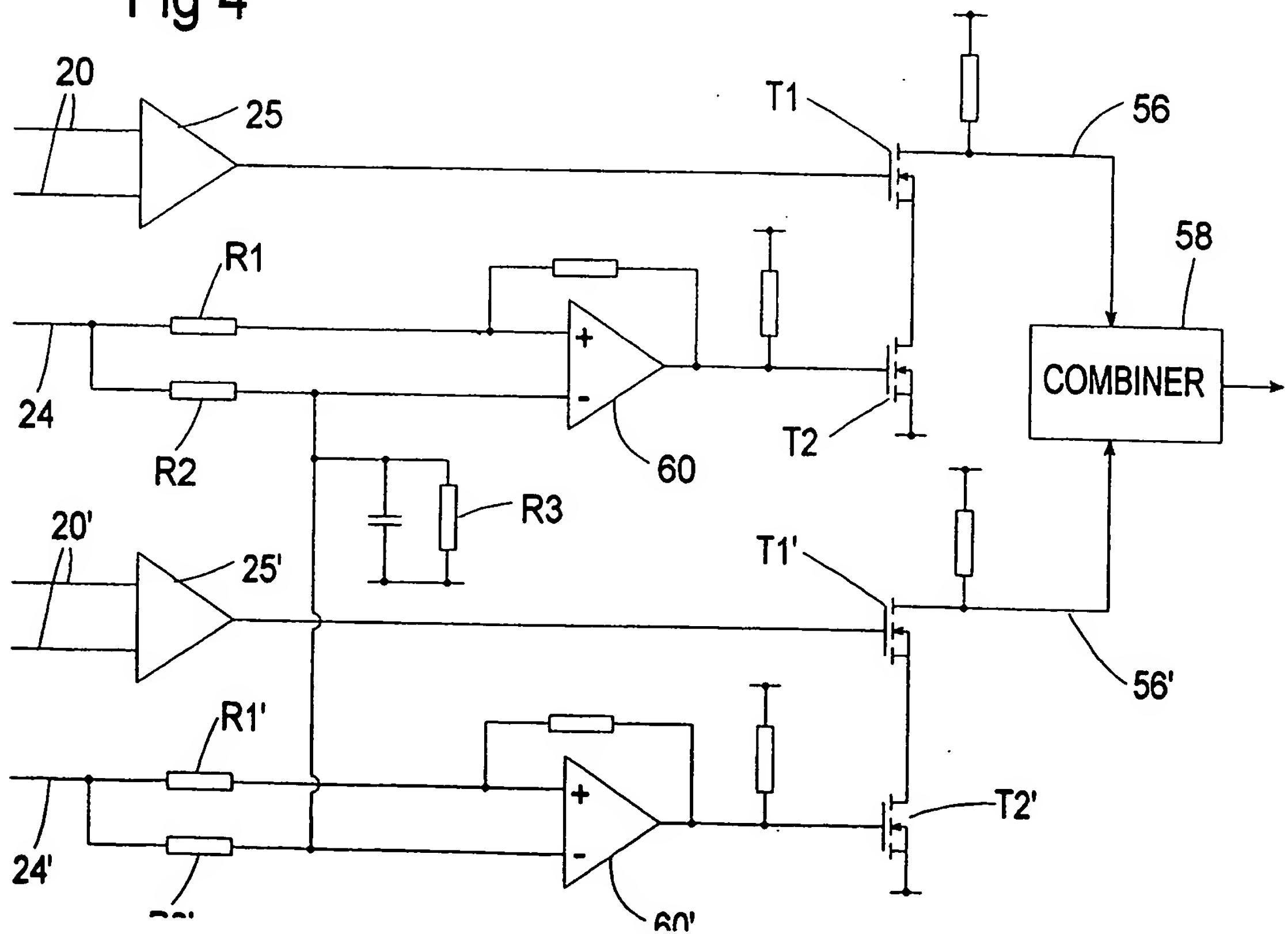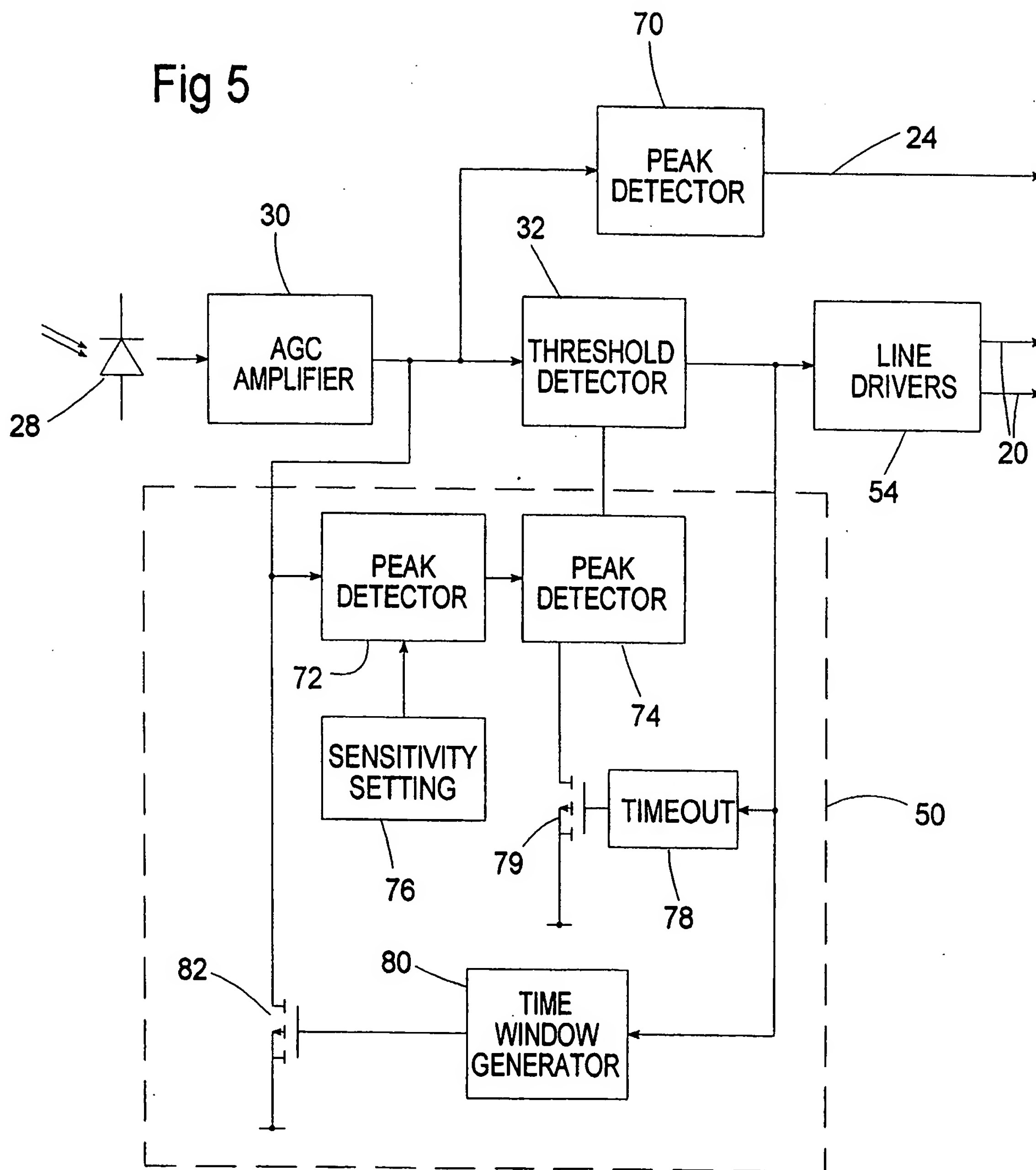
Fig 3B

Fig 4

Fig 5

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   H04B10/06   H04B7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 95 28615 A (MARPOSS APP ELETT ;CARLI CARLO (IT); FERRARI ANDREA (IT)) 26 October 1995	10,11
A	see abstract; figures 1,4	1
Y	IBRAHIM M M ET AL: "PERFORMANCE ANALYSIS OF OPRICAL RECEIVERS WITH SPACE DIVERSITY RECEPTION" IEE PROCEEDINGS: COMMUNICATIONS, vol. 143, no. 6, 1 December 1996, pages 369-372, XP000679500	10,11
A	see page 369, left-hand column, paragraph 1 - right-hand column, paragraph 2; figure 1 see page 370, left-hand column, paragraph 1 - right-hand column, paragraph 1	1,2,4,8

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[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the International search	Date of mailing of the International search report
2 June 1999	14/06/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	FR 2 567 700 A (EBL) 17 January 1986 see abstract; figure 1 see page 1, line 7 - page 2, line 9 -----	1,3,7, 10,11,13
A	FR 2 567 700 A (EBL) 17 January 1986	1,3,7, 10,11,13

2

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			EP	0756694 A	05-02-1997
			JP	9512336 T	09-12-1997
			US	5778550 A	14-07-1998
FR 2567700	A	17-01-1986	NONE		

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Photocouplers: Performing Big in Small Spaces

The current development trend in photocouplers is targeting smaller packages, lower cost, higher reliability, higher operating speed, and lower power consumption, which corresponds with the requirements for electronic devices in the future.

Defining the Photocoupler

The primary function of a photocoupler is to provide electrical isolation through an optical source. A photocoupler comprises both a light emitting diode (LED) and a photodetector in one package. When a voltage (current) is applied, the LED converts an electrical signal into an optical one. The photodetector receives the optical signal and converts it back into an electrical signal, forming an isolation interface in the circuit (see Figure 1).

The internal structure of the photocoupler can be generally divided into two categories—reflective and face-to-face. In reflective structures, the LED and photodetector are mounted horizontally on the same surface of the frame. When light is emitted from the LED, it passes through the transparent silicon resin and reflects to the photodetector through a barrier located between the epoxy resin and the external mold. In face-to-face structures, the LED and photodetector are mounted on separate frames facing each other (see Figure 2). During production, the reflective structure has the advantage of a single frame, enabling an increase in the capacity and efficiency when compared to the face-to-face structure.
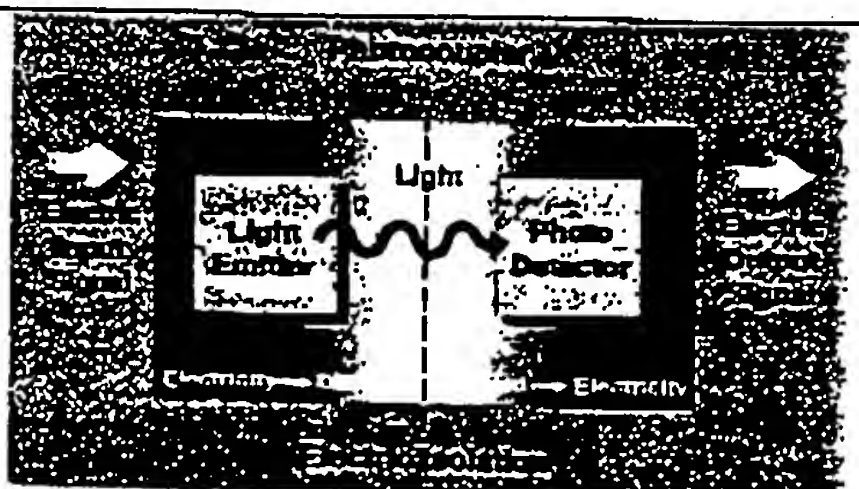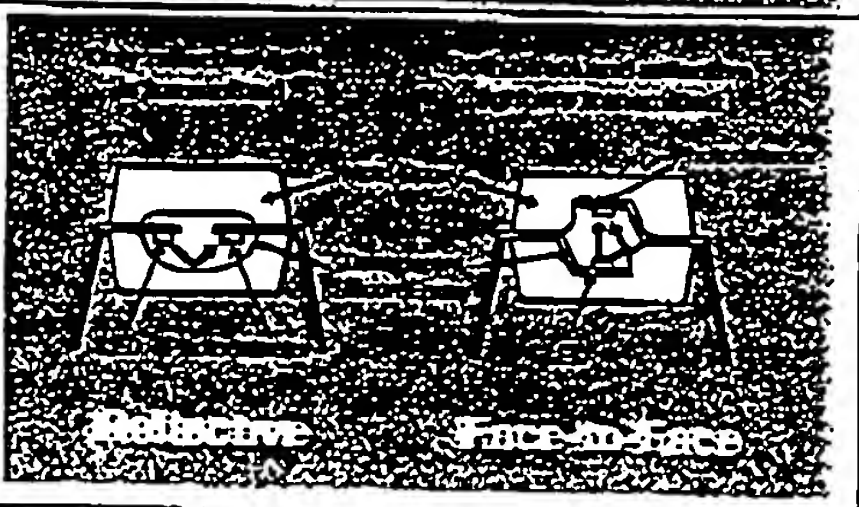

Figure 1:
The Basic
Function of
Photocouplers

Figure 2:
Internal
Structure of
Photocouplers

Advantages of Photocouplers in System Design

Photocouplers are typically designed to isolate electrical output from the input in order to eliminate the noise, which was formerly a function for relay and pulse transformers. In today's technology environment, widespread usage of the microcomputer has created a number of new applications for photocouplers. The components can solve various system design issues, including the connection of different voltages, elimination of noise, and the protection of the end-user from electrical injuries. Each of these issues will be addressed throughout the article as they relate to the various photocoupler types.

Choosing a Photocoupler

Essentially, photocouplers are categorized by their output function. Photocouplers available to today's design engineers include:
- phototransistor output couplers
- high-speed photo IC couplers
- phototriac-output couplers and photothyristor-output couplers
- MOSFET-output couplers (also called photorelays)

There are many applications for photocouplers. For example, a cell phone battery charger is one of the key applications within the household equipment category, primarily because the charger functions as a switching power supply device and requires a photocoupler to stabilize the output voltage. In addition, inverters inside air-conditioners and other white goods applications utilize photocouplers because there is usually a microprocessor controlling the alternating current (a.c.) loads (e.g., inverter motor, fan motor, heater, and electromagnetic valve). If the microprocessor is directly connected to the a.c. load electrically, it may be influenced by the noise from the a.c. load, and thereby result in a malfunction. The photocoupler is able to protect the microprocessor from the noise by isolating it from a.c. loads electrically.

In computer and office automation equipment, a high-quality power supply unit is provided to supply the stabilized direct current (d.c.) power. The switching power supply is used in the power unit to guarantee the stabilization in general, and a photocoupler is used in the switching power supply.

Finally, industrial applications require photocouplers in

many systems because the majority of automation machines require a programmable logic controller (PLC). The PLC also controls some of the a.c./d.c. loads with a microprocessor, so the photocoupler is used to protect the microprocessor. The number of control nodes in the automation machine determines the numbers of phototransistor couplers that are required.

Designing with Photocouplers
Phototransistor Coupler
The transistor coupler is the most commonly used photocoupler. Figure 3 shows the typical circuit of a transistor coupler.

When designing with a transistor coupler, current transfer ratio (CTR) is an important parameter to consider. The current transfer ratio of a photocoupler indicates the rate of the output current (I_C) of its phototransistor to a forward input current (I_F) flowing through its LED. It is defined by:

$$CTR = \frac{I_C}{I_F} \times 100\%$$

Table 1 is an example of CTR specification on the datasheet.

Characteristics	Symbol	Test condition	Min.	Typ.	Max.	Unit
Current Transfer Ratio	I_C / I_F	I_F=5mA, V_{CE}=5V	50	—	600	%
		Rank 6B	100	—	600	%

Table 1: CTR Specification for Transistor Photocouplers

After the CTR is determined, the design engineer should decide the load resistance R_L by considering the latter circuit. When R_L is assumed to 2,000 ohms in this case, necessary I_C is expressed by:

$$I_C = \frac{(V_{CC} - V_{CE}(Sat))}{R_L} = \frac{(5V - 0.1V)}{2K\Omega} = 2.45mA$$

V_{CE}(Sat) is described in the data sheet. V_{CC} is determined by the designer.

After I_C is determined, I_F current is determined by using I_C-I_F curve, I_C-T_a curve, and CTR (I_C) degradation curve in the data sheet. The designer should add some margin into the calculated I_F.

After I_F is determined, input resistance R_{in} is calculated by:

$$R_{in} = \frac{(V_{CC} - V_F - V_{OL})}{I_F} \text{ in which,}$$

V_F: Forward voltage of LED and V_{OL}: Output ON voltage of Logic IC.

High-Speed IC Coupler
Figure 4 shows a typical circuit of high-speed IC couplers. Compared to the transistor coupler, which is operated for analog functions, the high-speed IC coupler is easier to design due to its digital characteristics. The following is an example of circuit design for 5-MHz pulse transmission. One important parameter for high-speed IC coupler is the input current threshold (I_{FH}). Table 2 is an example of I_{FH} shown on the datasheet.

Characteristics	Symbol	Test condition	Min.	Typ.	Max.	Unit
"H Level Output → L Level Output" Input current	I_{FH}	I_{OL}=13mA, V_F=2V V_{OL}=0.6V	-	-	5	mA

Table 2: Input Current Specification for High-Speed IC Couplers

I_{FH} is defined as the value of the input current when the output node is turned on. Since the value may vary by part, only the maximum is specified on the datasheet. For example, Table 2 guarantees that if the input current is 5 mA, the output node will be turned on. The data has already guaranteed that the temperature

ranges from 0°-70°C.

The designer should decide I_F by considering LED degradation data D_t on the data sheet. Assuming the life coefficient D_t is 0.89, I_F is calculated by:

$$I_F = \frac{I_{FH}}{D_t} = \frac{5mA}{0.89} = 5.6mA.$$

Likewise, designers should add some margin to I_F and obtain the R_L using a calculation similar to that used for the transistor couplers.

Phototriac and Photothyristor Coupler
Unlike transistor couplers or high-speed IC couplers, which perform d.c. signal transmission between the input and the output sides, triac couplers can control the a.c. load at the output by a d.c. signal at the input. Because of its a.c. control features, a 400-V coupler is used for a 100-V a.c. load, and a 600-V coupler is used for a 200-V a.c. load. Figure 5 is the example of triac coupler circuit. The typical a.c. load includes solenoid bulbs, a.c. motors, and a heater. Table 3 is an example of the LED trigger current.

Coupled electrical characteristics (T_a=25°C)

Characteristics	Symbol	Test condition	Min.	Typ.	Max.	Unit
Trigger LED Current	I_{FT}	V_T=6V	-	-	10	mA

Table 3: Input Current Specification for Triac Photocouplers

I_{FT} is defined as the value of the input current when output node is turned on. Since the value may vary by part, only the maximum is specified. For example, Table 3 guarantees that if the input current is 10 mA, the output node will be turned on. The designer should decide I_F by considering the I_{FT}-T_a curve and LED degradation data of the data sheet. Assuming temperature coefficient D_{T_a} is 1.4 and life coefficient D_t is 0.89, I_F is calculated by:

$$I_F = I_{FT} \times DT_a / D_t = 10mA \times 1.4 / 0.89 = 15.7mA$$

Adding some margin into the calculated I_F, the input resistance R_{in} can be obtained using the same method introduced previously.

Photorelay
The photorelay is a MOSFET-output photocoupler. Figure 6 shows a typical circuit of photorelay. It was named a photorelay because its operation and characteristics are the same as those of a conventional mechanical relay. When transmitting and switching small analog signals, the conventional photocoupler typically distorts the waveform of the signal due to its large offset voltage on the output side. Therefore, a mechanical relay is used in the circuit where small analog signals are controlled. However, the problems associated with mechanical relays, including reliability issues, high power consumption, and lower switching speeds, have created an increasing demand for an equivalent semiconductor device, which led to the development of photorelay devices.

The features of the photorelay when compared with mechanical relays include high reliability, space savings, high speed, low drive power consumption, and noise-free operation. In addition, it also has the advantage of both a.c. and d.c. functions, is free of errors caused by dV/dt, and has a very small leakage current with no offset voltage. Table 4 is an example of the LED trigger current.

Coupled electrical characteristics (T_a=25°C)

Characteristics	Symbol	Test condition	Min.	Typ.	Max.	Unit
Trigger LED Current	I_{FT}	I_{SW}=120mA	-	2	3	mA

Table 4: Input Current Specification for Photorelay

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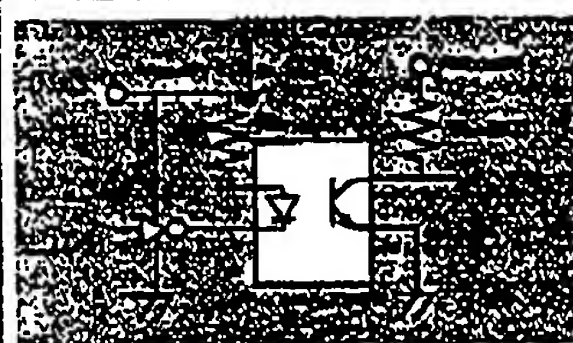---

Engineering   APPLIANCE ENGINEER

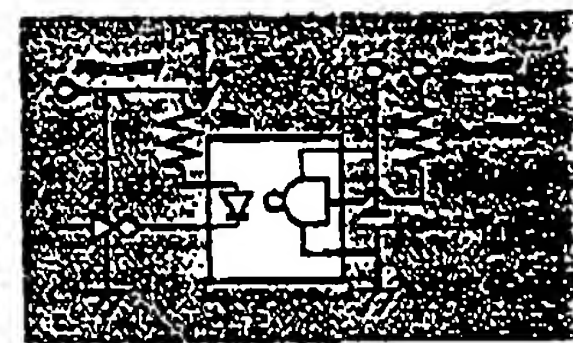Figure 3: A Typical Circuit of Transistor Coupler
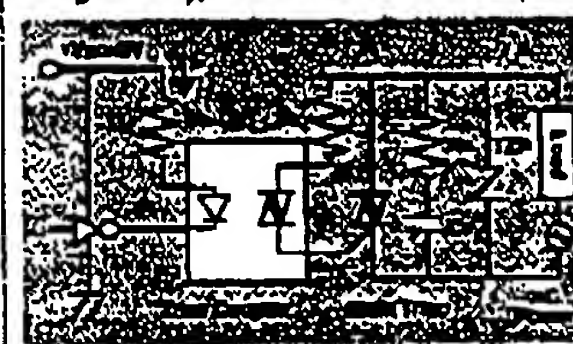Figure 4: A Typical Circuit of High Speed IC Coupler
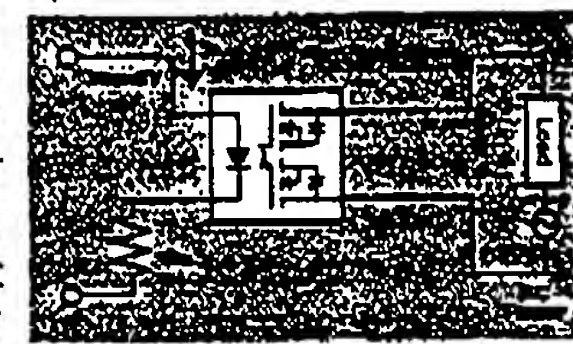Figure 5: A Typical Circuit of Triac Coupler
Figure 6: A Typical Circuit of Photorelay

Figures 3-6

I_{FT} is defined as the value of input current when output node is turned on. Again, since the value may vary by part, only the maximum is specified. The designer should decide I_F by considering the I_{FT}-T_a curve and LED degradation data of the data sheet. Assuming temperature coefficient D_{Ta} is 1.3 and life coefficient D_t is 0.89, I_F is calculated as follows:

$$I_F = I_{FT} \times D_{Ta} / D_t = 3mA \times 1.3 / 0.89 = 4.4mA$$

Adding some margin into the calculated I_F, the input resistance R_{in} can be determined using the same method introduced previously.

Future Design Trends

As discussed in the article, photocouplers are designed into a wide variety of applications. The current development trend is targeting smaller packages, lower cost, higher reliability, higher operating speed, and lower power consumption, which corresponds with the requirements for electronic devices in the future.

Among the various categories of photocouplers, the applications and the demand for photorelays (MOSFET output) are expected to expand rapidly in the future. Currently, mechanical relays have a large market in various applications such as telecommunication line switches, modems, and testing equipment. Modem applications include PCMCIA cards for personal computers, ADSL modems, set-top boxes, and facsimile machines. Testing applications include memory testers, logic testers, test recorders, and other general equipment. Those applications using mechanical relays will require a photorelay because of the demand for high reliability, small packaging, and low power consumption. Most of the mechanical relays remain strong in the current market because of the cost advantage. Therefore, most photorelay suppliers are working on of the development of new semiconductor technology to drive costs down. The improved cost of the photorelay will strengthen its presence and eventually establish a leading position in the relay market. ⊘

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